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EVALUATION OF EFFECTS OF CABLE LENGTH ON ACCELEROMETER RESPONSE

by

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1.0 BACKGROUND

The Advanced Photon Source (APS) machine features a storage ring with a radius of 553.5 ft. Ground motion at the APS site will be studied by simultaneously measuring response at seven (7) locations. As illustrated in Fig. 1, the selected locations correspond to the center of the storage ring and 60° compass points. With the battery-powered instrumentation amplifiers and 7-channel tape recorder located at the site center accelerometer cable lengths of 628 feet (the outer radius of the experimental hall) are required. To allow for changes in the terrain and other contingencies, 675 ft cables will be used.

2.0 OBJECTIVES

Determine the effects of the 675 ft cable length on accelerometer performance, viz., amplitude and frequency response. Evaluate the transfer function of the PCB 180A10 integrating amplifier when operated in the velocity and displacement modes.

3.0 THEORETICAL RESPONSE

The resistance of 675 feet of RG 58 coaxial cable is approximately 6.63 ohm with a shunt capacity of 0.0185 microfarad. The electrical circuit of the accelerometer channel, see Fig. 2a, includes an A.C. signal source with less than 100 ohm internal resistance representing the accelerometer, and a 6.63 Ω series resistor and a 0.0185 ufd capacitor representing the cable, which is terminated in a signal conditioner and/or tape recorder with greater than 10 K ohm input resistance. For system frequency response calculations the 6.63 ohm and 10 K ohm resistors can be neglected and to be conservative the accelerometer internal resistance can be assumed to be 100 ohms. These assumptions lead to the equivalent electrical circuit in Fig. 2b. The transfer function between output (e_o) and input (e_{in}) can be written as

$$\frac{e_o}{e_{in}} = \frac{1}{1 + 100\ \omega c} \tag{1}$$

where $\omega = 2\pi f$, f is frequency in Hz and c is capacitance in farads. Values of the transfer function (e_o/e_{in}) as a function of frequency are given in Table 1. These values vary from 1.00 at 1 Hz to 0.994 at 500 Hz. From a theoretical standpoint, no attenuation in signal is to be expected up to a frequency greater than 500 Hz.

4.0 MEASURED RESPONSE

The basic test configuration is shown in Fig. 3. An electromagnetic exciter provides sinusoidal motion to the accelerometer; displacement response is measured with a displacement transducer. For sinusoidal excitation, acceleration is related to displacement by

$$g = 0.1022\ Df^2 \tag{2}$$

where g is acceleration in g's and D is displacement in inches.

Tests were conducted using both a short 3-ft cable and the 675-ft RG 58 cable. Figure 4 shows the results of two test runs.

The test fixture was adapted from a previous experiment and several spurious resonances were observed at approximately 60 Hz and 150 Hz in the Run 1 data. Run 2 data was obtained after a modification to the displacement transducer mount. Results are within the anticipated experimental error and indicate that the 675-ft cable does not alter transducer response.

To verify the operation of the 180A10 amplifier as a double integrator two methods were used: (1) A transfer function determined from input-output voltages at various frequencies, and (2) An actual operating test in which the accelerometer was vibrated with the test configuration of Fig. 3 and the displacement obtained by double integration of the acceleration signal is compared with the directly measured displacement. With both methods, it was determined to be necessary to increase the calibration factor, determined from the operation manual, by a factor of $\sqrt{2}$ to achieve satisfactory results. Results obtained from application of method 2 are shown in Table 2.

Low frequency response attenuation, at frequencies less than 10 Hz, can clearly be seen. The manufacturer's specifications call for a -5 Db attenuation at 5 Hz which compares well with a measured -5.56 Db attenuation. Midrange frequency response, from 10 Hz to 50 Hz, are acceptable for this type of measurement, while the higher frequencies, 60 Hz to 100 Hz, show various amounts of attenuation. The attenuated high frequency response can be attributed to resonant frequencies of the test fixture and poor coupling between the accelerometer and the brass target required for the displacement transducer, rather than to inaccuracies in the integrating circuit.

Velocity response was measured with the long cable length using the integrating amplifier (180A10). Velocity was also calculated from measured displacement using the relationship

$$V = 6.28\ Df\ . \tag{3}$$

The results are compared in Table 3. Data trends are similar to those of displacements. For operation in the velocity mode, specifications call for an attenuation of -3 Db at 5 Hz with the actual measured value of -3.44 Db which is considered acceptable. Again, data correlation is acceptable for this type of measurement.

Considering the error in the calibration factor constant with the double integrator it was necessary to verify the acceleration output of the 180A10 using method 2. Acceleration was calculated by use of Eq. (2) and compared to the direct measurement value obtained with the 393 C accelerometer, 675-ft cable, and the 180A10 signal conditioner used in the acceleration mode. Test results, Table 4, indicate the unit to be operating properly. The scatter in the data is reasonable in consideration of the f^2 value required in Eq. (2). Again, the data around 60 Hz was influenced by a test fixture resonance.

5.0 CONCLUSION

The test results demonstrate that, over the frequency range of interest, there will not be any unwanted signal attenuation with 675-ft of RG 58 cable connecting the PCB model 393C accelerometer to the PCB model 180A10 signal conditioner.

A displacement factor error in the manufacturer's operating manual was discovered. Accounting for this error, the unit can be expected to yield accurate field measurements. The manufacturer's representative has been notified of the error.

Table 1. Transfer Function for Various Frequencies

Freq (Hz)	ωc	$\frac{e_o}{e_i}$
1	1.162×10^{-7}	≈ 1.00
5	5.814×10^{-7}	≈ 1.00
10	1.162×10^{-6}	≈ 1.00
50	5.814×10^{-6}	≈ 1.00
100	1.162×10^{-5}	≈ 1.00
200	2.326×10^{-5}	0.998
500	5.814×10^{-5}	0.994

Table 2. Comparison of RMS Displacements Measured by Method 2

Frequency Hz	Displacement (Disp. Transducer) mils RMS	Displacement (180A10 - 393C) mils RMS	Disp. (180A10) / Disp. (Disp. Trans)
2	4.93	0.128	0.0260
3	4.40	0.147	0.0334
4	3.88	0.859	0.221
5	3.49	1.84	0.527
6	3.13	2.33	0.744
8	2.62	2.43	0.927
10	2.22	2.15	0.968
15	1.63	1.64	1.01
20	1.23	1.26	1.02
25	0.956	0.996	1.04
30	0.735	0.770	1.05
40	0.407	0.439	1.08
50	0.224	0.238	0.975
60	0.205	0.192	0.936
70	0.161	0.133	0.826
80	0.110	0.0988	0.898
90	0.104	0.0747	0.534
100	0.0981	0.0599	0.61

Table 3. Comparison of Measured to Calculated RMS Velocity

Frequency, Hz	Displacement (Disp. Trans.), mils RMS	Velocity (Calculated), in./sec	Velocity (180A10 - 393C), in./sec	Velocity (180A10) / Velocity (Disp. Trans.)
2	9.73	0.122	0.00995	0.0816
3	8.38	0.157	0.0244	0.155
4	7.82	0.196	0.0863	0.440
5	6.26	0.196	0.134	0.673
6	5.45	0.205	0.166	0.809
8	4.41	0.222	0.204	0.919
10	3.71	0.233	0.216	0.927
15	2.59	0.244	0.231	0.946
20	1.92	0.241	0.229	0.950
25	1.43	0.225	0.216	0.960
30	1.07	0.202	0.196	0.970
40	0.614	0.154	0.153	0.993
50	0.377	0.118	0.106	0.898
60	0.304	0.115	0.0999	0.868
70	0.236	0.103	0.0818	0.794
80	0.141	0.0885	0.0690	0.780
90	0.132	0.0746	0.0598	0.802
100	0.118	0.0741	0.0525	0.708

Table 4. Comparison of Measured to Calculated RMS Acceleration

Frequency, Hz	Displacement (Disp. Trans.), mils RMS	Acceleration (Calculated), g rms	Acceleration (180A10 - 393C),	Acc. (180A10) / Acc. (Disp. Trans.)
0.5	43.7	0.00111	0.00115	1.03
1.0	40.3	0.00412	0.00345	0.837
2.0	24.8	0.0101	0.00942	0.933
3.0	21.2	0.0194	0.0182	0.938
4.0	18.3	0.0299	0.0282	0.943
5.0	55.3	0.141	0.127	0.901
10	31.8	0.343	0.308	0.951
15	21.7	0.499	0.472	0.946
20	15.5	0.663	0.599	0.947
25	10.1	0.645	0.677	1.05
30	7.88	0.724	0.705	0.974
40	4.40	0.719	0.721	1.00
50	2.86	0.730	0.635	0.869
60	2.05	0.750	0.653	0.866
70	1.52	0.761	0.615	0.808
80	0.772	0.505	0.600	1.18
90	0.664	0.549	0.581	1.06
100	0.582	0.594	0.632	1.04

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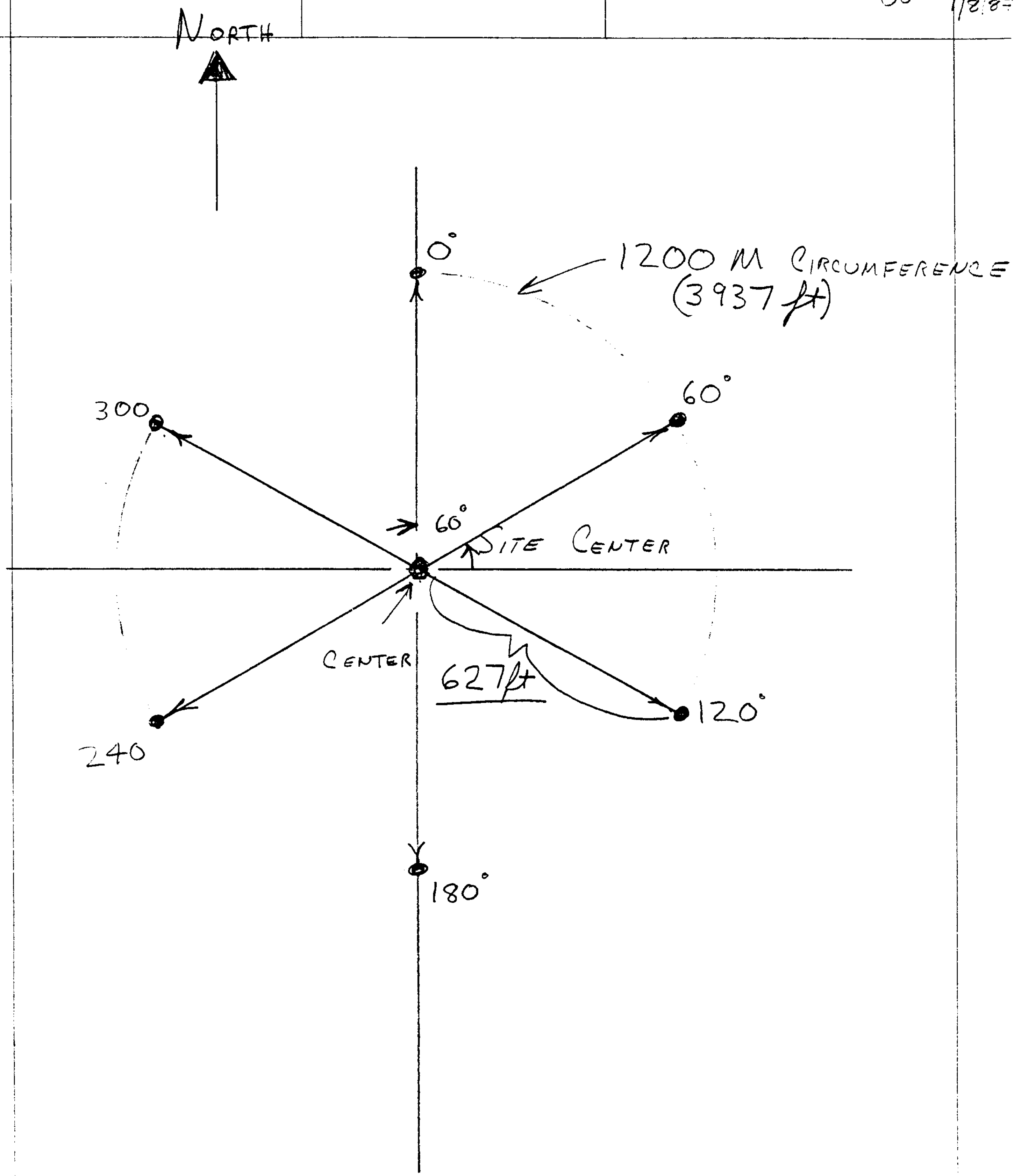

Fig. 1. Site Measurement Locations

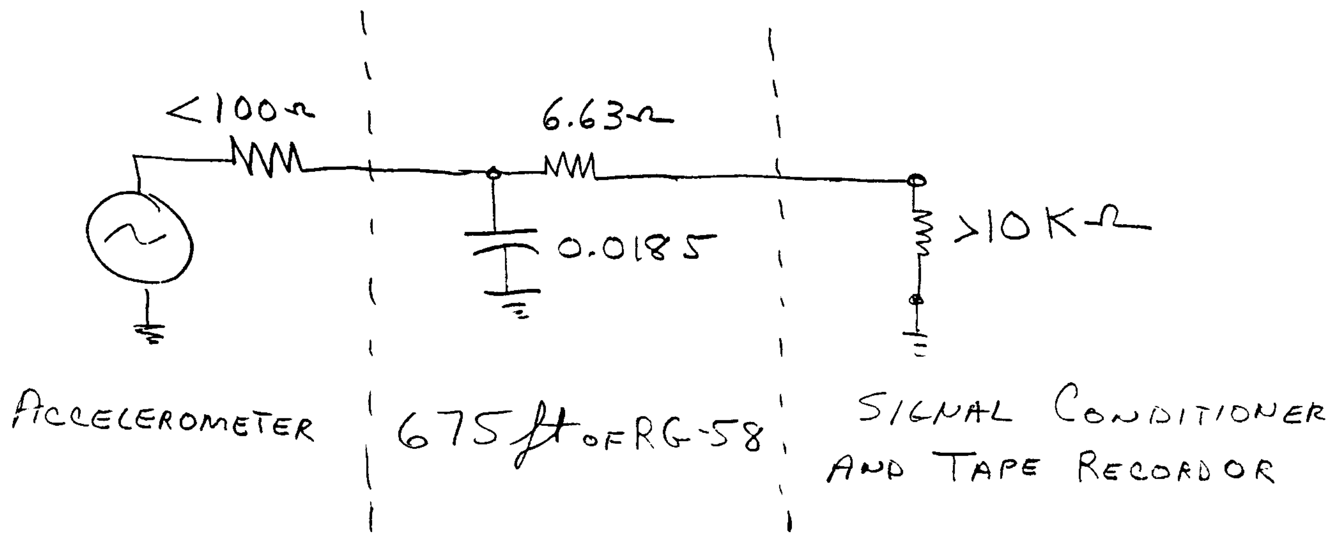

Fig. 2a. Electrical Circuit

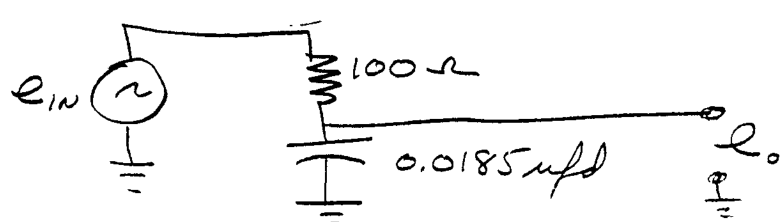

Fig. 2b. Equivalent Electrical Circuit

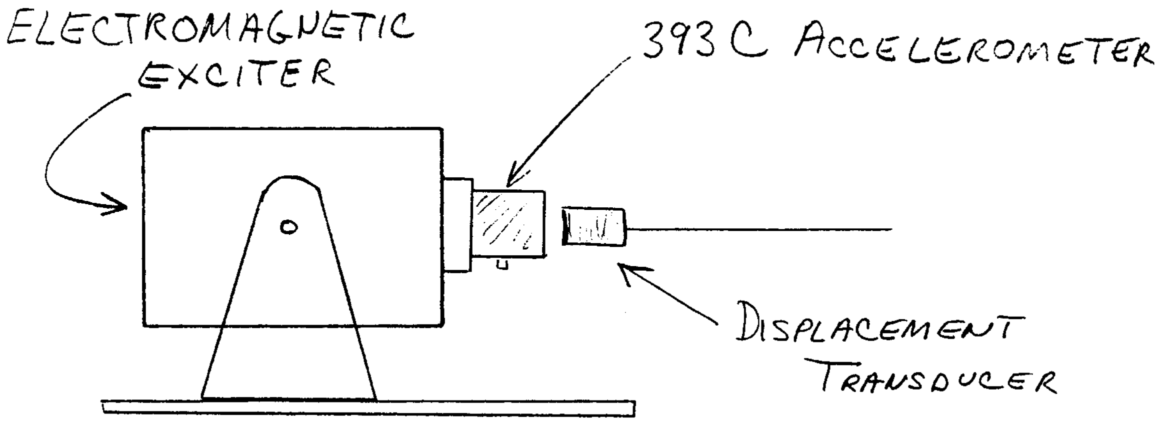

Fig. 3. Test Configuration

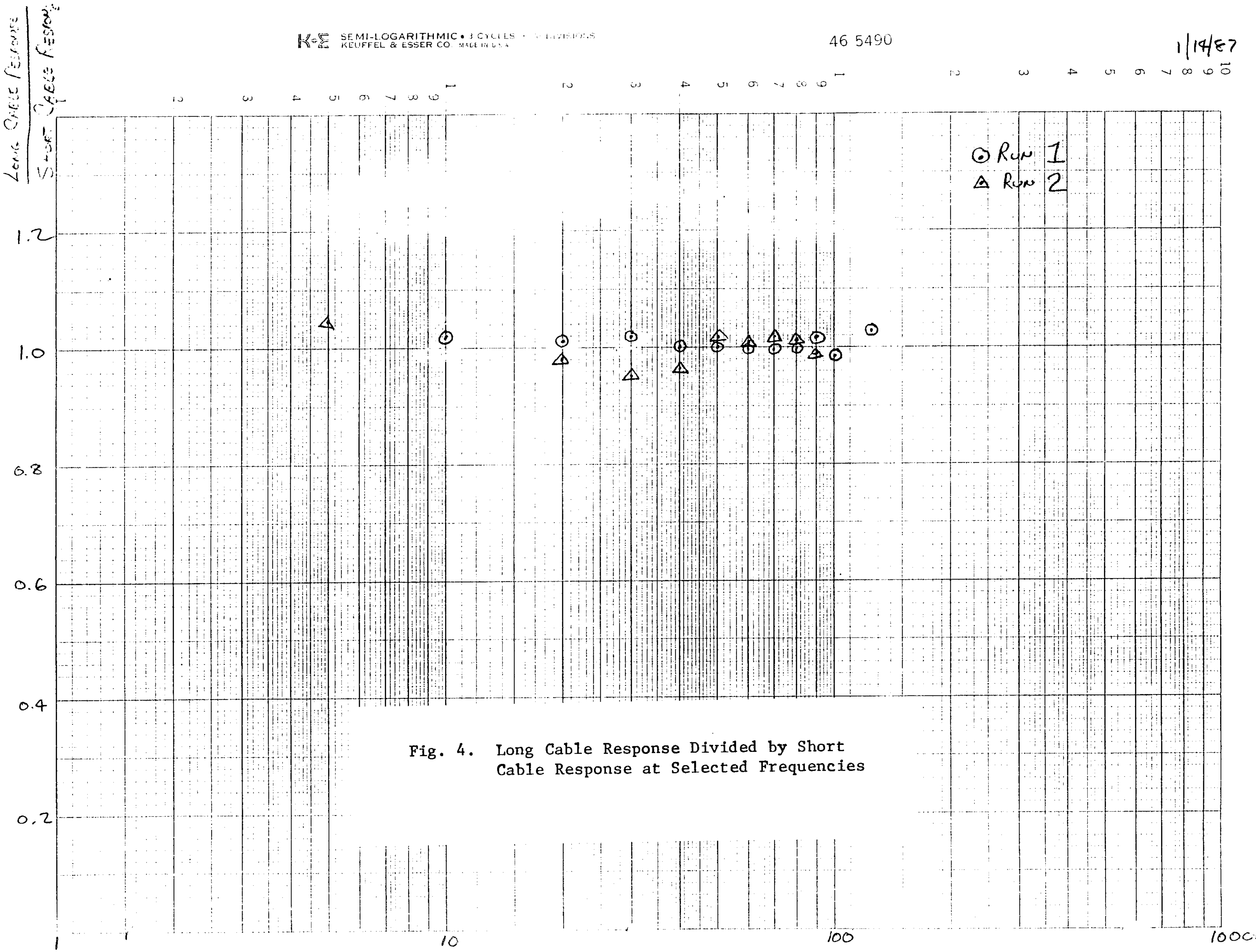

Fig. 4. Long Cable Response Divided by Short Cable Response at Selected Frequencies